Introduction to semiconductor qualification and reliability assessment

David Ortiz

IEEE 802.3cz Task Force - 15th Dec 2020 Adhoc Meeting

Introduction & objectives

- For electronic components, automotive reliability assessment is generally considered to be equivalent to:
  - Determine component grade (maximum operating temperature of the component).
  - Determine which AEC-Qxxx document covers qualification for the type of component (AEC-Q100 for Integrated Circuits, AEC-Q101 for discrete semiconductors, …).
  - Extract the mandatory tests to be executed, and the specific conditions for each test.
  - Execute the mandatory tests.
  - Check no fails after the tests.
  - And that’s it!
- However, although the previous steps are essential for guaranteeing reliability of electronic components, they are not enough, and a more complete approach is needed to guarantee the reliability.
  - This approach is covered by:
    - SAE-J1879 standard
    - Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications published by ZVEI
  - On this presentation this approach to advanced reliability assessment is described.

Limitations of the basic approach

- AEC-Qxxx documents are generic, and can not cover all use scenarios, and all possible failure modes of electronic components.
  - *Specific stress conditions that are listed in AEC-Qxxx documents are tailored to cover a single failure mode, for one specific Mission profile.*
    - *As an example, in AEC-Q100, for grade 2 components HTOL experiment of 1000 hours at temperature of 125 ºC is required.*
      - *Derived from the following Mission Profile and Reliability model:*
        - *Mission profile: 12000 hours @ average T_J = 87 ºC*
        - *Reliability model: Failure mode acceleration with temperature following Arrhenius equation with activation energy of 0.7 eV.*
- *For new technologies, products with significantly different thermal performance, the stress conditions and durations described in AEC-Q100 might not be enough.*
  - *If the component has major failure modes with significantly lower activation energies, the 1000 hours of the HTOL experiment might not be enough.*
- *Mission profile considering just a single average temperature is not accurate.*
  - *Required HTOL duration can vary dramatically for slightly different temperature spectrums for a given failure mode with given activation energy.*

Advanced Reliability Assessment

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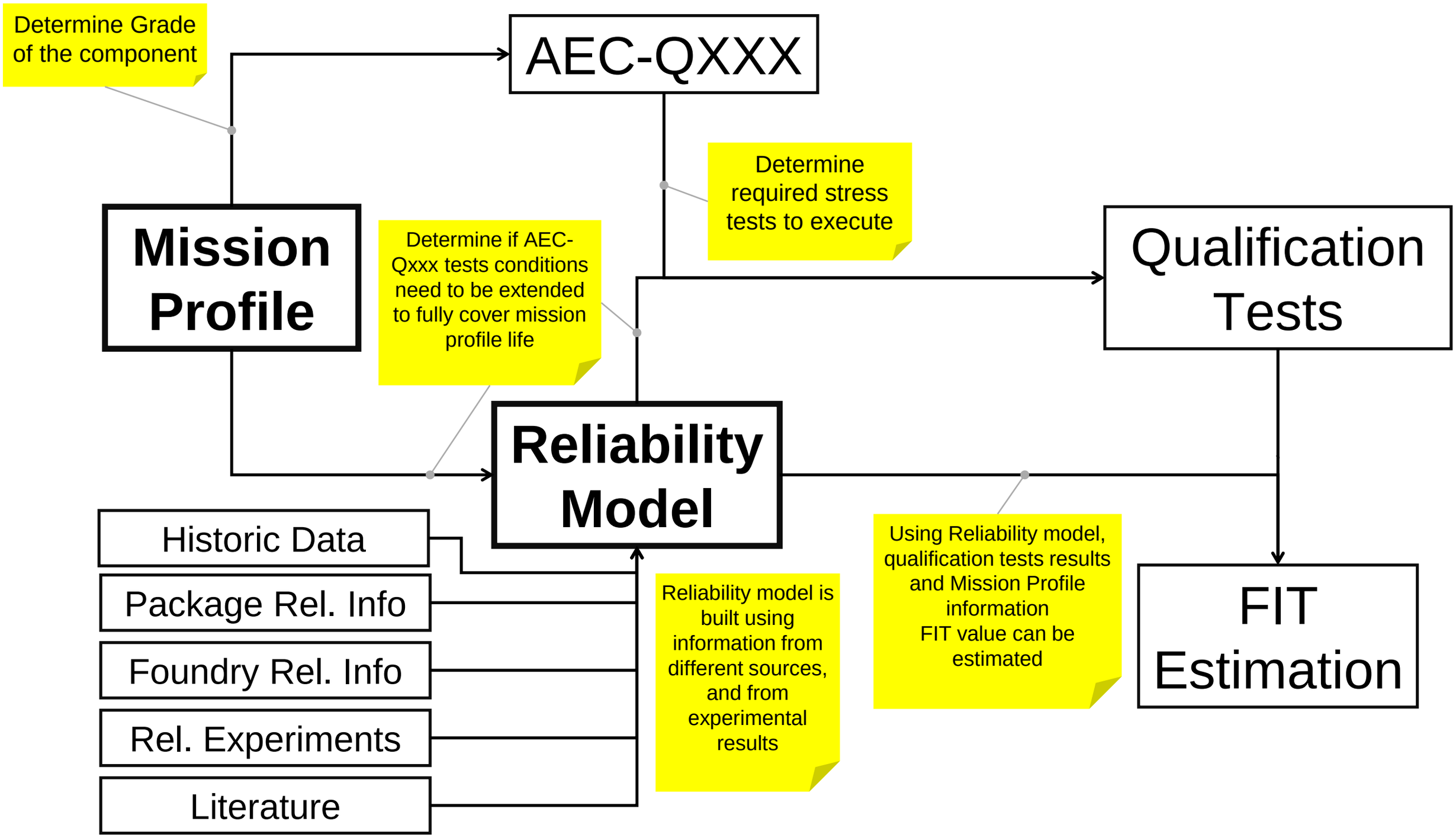
Advanced Reliability Assessment I

- One definition of reliability:
  - *The probability that an item will perform a required function without failure under stated conditions for a stated period of time.*
- Actual use conditions are key to the reliability assessment, and also impact the qualification strategy.
  - The use conditions are described by the Mission Profile.
- To do any analysis of the reliability of an electronic component, it is needed to consider which are the possible failures that can occur during the lifetime of the component, and how they are affected by the different environmental conditions.
  - This is typically described as the Reliability Model of the component.
    - The reliability model is the compilation of the major failure modes that can affect the reliability of the component.
    - For each failure mode, it describes which factors affect the failure rate, and how those factors contribute to it.
      - As typical use examples, Black's equation is typically used to model electromigration induced failures, Coffin-Manson is typically used to model mechanical failures induced by temperature cycling, …
      - Using this knowledge, acceleration factors for the qualification stress tests can be derived.
      - The acceleration factors are then used in the design of the stress tests to guarantee that they cover adequately the life time of the device according to the Mission Profile.
    - It is specific to each component or component family, and is based on accelerated stress test results, data available from the different providers, literature, …

Reliability Assessment II



Mission Profile

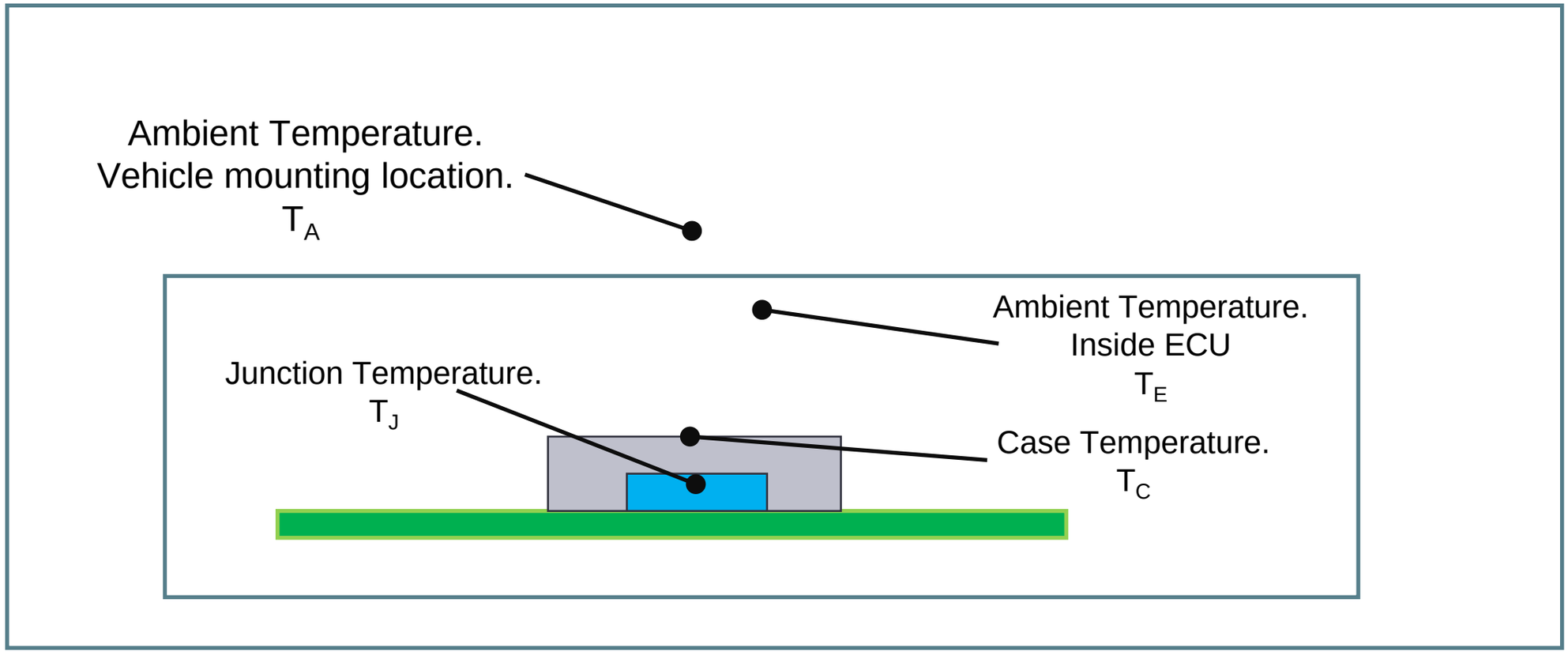
- Mission profile:
  - Summarizes the key static and dynamic conditions that the component will be exposed to during its lifetime.
    - Temperature conditions
      - Ambient temperature histograms (ECU ambient, or Car ambient temperature plus estimation of ECU self-heating, so ECU ambient temperature can be derived).
      - Temperature cycling histograms.
    - Electrical conditions
    - Mechanical conditions
      - Vibrations
        - Might not be critical for the semiconductor component, but it might have an effect on the connectors and the communication channel.
      - Mechanical loads
        - Might not be critical for the semiconductor component.
    - Climate conditions
      - Humidity, temperature-humidity cycles.

Ambient temperature I

- For semiconductor components, the failure modes that are accelerated by temperature depend on Junction Temperature.
- But Junction temperature depends on each component:
  - Each component has a different thermal resistance, depending on the type of package.
  - Each component has a different power dissipation.
- Mission profile needs to be more generic, and contain only ambient temperature.
  - It is desirable that Mission Profile definition already provides ambient temperature inside the ECU.
  - This allows for a generic definition of Mission Profile, but also contains enough detailed information to help component manufacturers to derive the required junction temperature information for the reliability assessment.

Ambient temperature II

- Active components, so temperature depends on location
  - Ambient temperature outside ECU.
  - Ambient temperature inside ECU.
  - Case temperature → on top of the semiconductor component case.
  - Junction temperature → active area of semiconductor components.
- Depends on specific power dissipation and thermal resistance of the different active elements.



Advanced Reliability Assessment Example

Reliability assessment example

- Use case: 1000Base-H transceiver for battery management system, implemented in a standard, automotive-qualified CMOS process using standard package.
- Mission Profile Temperature Spectrum:
  - Total use time 32000 hours.

Percentage	6%	20%	65%	8%	0.9	0.1%
Hours	1920	6400	20800	2560	288	32
ECU Ambient Temperature	-40	53	70	90	105	110

- Reliability model:
  - Total of 10 different failure modes were considered, with activation energies between 0.2 and 0.9 eV.
  - The most critical ones: GOI, HCI, NBTBI, EM, TDDB
- HTOL test conditions:
  - 1400h, T_J=140 ºC, Core supply = nominal value + 13%.
  - The above mentioned conditions are significantly more stringent than the ones specified in AEC-Q100 for grade 2 components.
  - The main reason for the differences are due to differences in the base reliability model, and the actual Mission profile of the component.

Mission Profile

Mission Profiles

- Considering only the temperature spectrum alone, there are already different Mission Profiles available in different standards. Some examples:
  - AEC-Q100:
    - 12000h use time. Average temperature for Grade 2 devices of 87ºC.
  - LV124:
    - 8000h driving time, indicates that depending on component use, other non-driving times should also be considered, like charging time, preconditioning, etc.
      - Different temperature spectrums are provided for different mounting locations ranging from -40 to 80 ºC, up-to -40 to 140 ºC.
- As indicated previously, mission profile has a very big impact on the reliability assessment at the component level. It is essential to agree on a base Mission Profile for OMEGA project to ensure component development and technology selection.
  - This affects all the components, but specially the VCSEL reliability, and the possible bias currents that can be used, which also has big influence on the link budget.

Mission Profile Proposal for 802.3cz

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Mission Profile proposal for 802.3cz

- Use time (power-on time): 12000 h.
- Total power-off time: 119400 h.
- Temperature Spectrum:

Percentage	6%	20%	65%	8%	1%
Hours	720	2400	7800	960	120
ECU Ambient Temperature	-40	23	70	100	105

- Temperature cycles: 54750 cycles, with average temperature delta of 76 ºC.
- Humidity: RH 74%, average temperature during on-time 87 ºC, average temperature during off-time 27 ºC.
- Mechanical vibrations: TBD.

Thank you!